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CRANFIELD INSTITUTE OF TECHNOLOGY

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RADIAL INFLOW TURBINE STUDY

THIRD INTERIM REPORT

by (QUALITY INSPECTED 1)

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United States Army

EUROPEAN RESEARCH OFFICE OF THE U.S. ARMY

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>The radial inflow turbine is a primary component used both in small gas turbines and turbochargers. Better understanding of the flow processes occurring within the small passages of the machine could well result in the improved design of units. As most of the detailed aerodynamics is still ill-defined, a joint research project with the objective of improving our understanding has been instigated by Cranfield, the US Army and Turbomach (San Diego).

This document gives the third report on the project. It describes the preparation of the rig stand and instrumentation for the machine. On-line data collection schemes and definitions of different parameters involved have been included. Problems faced while running the unit are identified together with solutions. The report includes preliminary test results of the turbine mapping.

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During the period starting from January 1990, attempts have been made to
complete the tasks discussed in the second interim report which included
the preparation of the rig stand, testing the operation of the turbocharger
(task 1) and taking the first set of laser measurements. The following
steps have been taken to achieve the goal.

The rig stand has been prepared which included the connection of the unit
to the main plant air and the provision of an upstream combustor. It also
includes the installation of an ejector at the outlet of the turbine.
Figure 1 is a diagram of the fully instrumented turbocharger in the test
cell. Venturitubes positioned upstream of the turbine inlet have been used
to provide the mass flow information. Valves V1,V2,V3,V4 and V5 have been
used to control the range of operating conditions of the machine.

At station 1 (figure 1) turbine inlet total pressure and temperature are
measured. Station 2 provides the same information at the outlet of the
turbine. At station 3 two pressure probes provide upstream venturitube
pressure and at station 4 two thermocouples measure the temperature.
Pressure tappings at station 5 along with those at station 3 give the
venturi differential required to calculate the mass flow.

The turbine test cell control room (with miscellaneous equipment) is shown
in figure 2. Located in the control area are the different valves throttle
control and data acquisition system. The turbine performance is
continuously calculated and updated on the display monitor (data can also
be printed in hard copy). Values for pressures and temperatures at
different stations are directly read by the computer and a programme has
been developed to calculate the desired parameters for the characteristic
curves of the turbine. Appendix A gives the definition and details of
various parameters used in the programme.

After the test rig was installed and the instrumentation was completed,
the turbine unit was tested. The first few tests revealed several unseen
problems which were overcome. At the initial phase the tubine unit was run

for fixed speeds ($N/\sqrt{T}$ = 15,30,40) and flow rate at the turbine inlet was controlled through different valves shown in figure (1). Variation in the expansion ratio across the turbine was observed with the mass flow. Maximum expansion ratio achieved in these tests was 3.5. Figure 3 shows the results obtained for various speeds. Comparing these results with test running points obtained from the data sheet provided by Turbomach, it was found that the mass flow was low. A detailed inspection of each component was carried out. Further investigation suggested that compressibility effects with the mass flow meter produced the problem. Correction of the formulae gave good agreement. In order to keep matters simple the venturitube mass flow meters have now been replaced by an orifice plate device.

The schemes have been defined for the installation of windows to provide the optical access for laser anemometry measurements. Two window positions downstream of the turbine rotor have been carefully chosen. Drawings are being prepared for machining the locations. The scheme involves a method for easy removal of the glass window for cleaning during the laser measurement. Figure 4 shows the locations selected for the optical access. In order to avoid any obstruction to the flow, window mounts have been designed to match the curvature cf the turbine casing. Figure 5 shows the proposed design of the arrangement.

During the rig testing it was observed that turbine outlet temperature can go subzero at large pressure ratios. The problem was discussed in the meeting with C Rodgers representing Turbomach and it was decided to keep the turbine outlet temperature above zero. It was also proposed that the pressure ratio at which laser measurement be made should be above 3.0 and velocity ratio should be kept at 0.75,0.65 and 0.55 (to be compatible with Turbomach measurements).

As mentioned above, the installation and initial commissioning of the rig has been carried out. It is expected that next interim report will provide laser anemometry results.

Amount of unused funds at the end of this period: $142,698

Property acquired during this period: None

R7.5-9/SJ

APPENDIX A

TURBOMACH TURBOCHARGER

INSTRUMENTATION AND PERFORMANCE CALCULATION USING TURBOMACH

PROGRAM

1. **MEASURED QUANTITIES**

   1.1 Atmospheric pressure   (in of Hg)

   1.2 Venturitube upstream pressure   (psi)

   1.3 Venturitube upstream temperature   (C^o)

   1.4 Venturitube differential   (in of Hg)

   1.5 Turbine inlet temperature   (C^o)

   1.6 Turbine outlet temperature   (C^o)

   1.7 Turbine inlet total pressure   (psi)

   1.8 Turbine outlet static pressure   (psi)

   1.9 Belmouth depression   (mm of H_2O)

   1.10 Speed   (rps)

2. **NOMENCLATURE**

P_1	Atmospheric pressure	(in of Hg)
P_2	Turbine inlet total pressure	(psi)
P_4	Turbine outlet static pressure	(psi)
P_3	Venturitube differential (h)	(in of Hg)
P_5	Venturitube upstream pressure	(psi)
T_1	Turbine inlet total temperature	(C^o)
T_3	Turbine outlet total temperature	(C^o)
T_5	Venturitube upstream temperature	(C^o)
NA	Rotation speed	(rps)

3. DATA CONVERSION

$$T_2 = T_1 - T_3$$

$$P_1 = P_1 * 0.491 \quad \text{(psi)}$$

$$T_1 = T_1 + 273.15 \quad \text{(A)}$$

$$T_3 = T_3 + 273.15 \quad \text{(A)}$$

$$P_3 = P_3 * 13.6 \quad \text{(in of } H_2O)$$

4. CALCULATION OF Cp AND $(\gamma - 1) / \gamma$, (C,G)

$$T = (T_1 + T_3) / 2$$

$$X = (T - 1125) / 875$$

$$C = (((((.0128 * X) - .007)*X - .0214)*X + .0371)*X + .278$$

$$G = 1.0 / 14.588 / C$$

5. PERFORMANCE CALCULATION

5.1 VOLUME FLOW

FROM BS1042

$$L = 359.1 * C_d * Z * d^2 * E * \sqrt{h} * \sqrt{W}$$

where

L = Actual flow   (lb/hr)

C_d = Coefficient of discharge = 0.986

Z = 1.0

$$E = 1/ \sqrt{(1.0 - m^2)}$$

$m = d^2 / D^2$

d = Venturi throat diameter = 0.925 in

D = Venturi upstream diameter = 3.23 in

h = Venturi differential = P_3 (in of Hg)

W = Density of fluid   (lb / ft^3)

$W = (P_5 * 144) / (R * T_5)$

$W = ((P_5 + P_1) * 144) / (R * (T_5 + 273.15))$

R = Gas constant

$L = 359.1 * C_d * d^2 * E * \sqrt{P_3 * 13.6} * \sqrt{W}$

$L = 303.97 * \sqrt{W * P_3 * 13.6}$ (lb / hr)

$L = 303.97 * \sqrt{W * P_3 * 13.6} / 3600$ (lb / sec)

L_s = Standard flow (lb / min)

$L_s = L * \sqrt{(T_5/288)} * (14.7/P_5) * 60$ (lb / min)

$Q(D)$ = Standard flow (ft / min or CFM)

$Q(D) = L_s / .0764$ (CFM)

$M(D)$ = Dimensionless mass flow = $L * \sqrt{T / P}$

$M(D) = L * \sqrt{(T_1 + 273.15)} / (P_2 + P_1)$

5.2 PRESSURE RATIO

$R(D) = (P_2 + P_1) / (P_4 + P_1)$

5.3 EFFICIENCY

$E = (T_2 / T_1) * (1.0 / (1.0 - (1.0 / R(D)) **G))$

where $T_1 = T_1 + 273.15$

and $T_2 = T_1 - T_3$ = Temperature change.

5.4 ROTATION SPEED

NA = Rotation speed (rps)

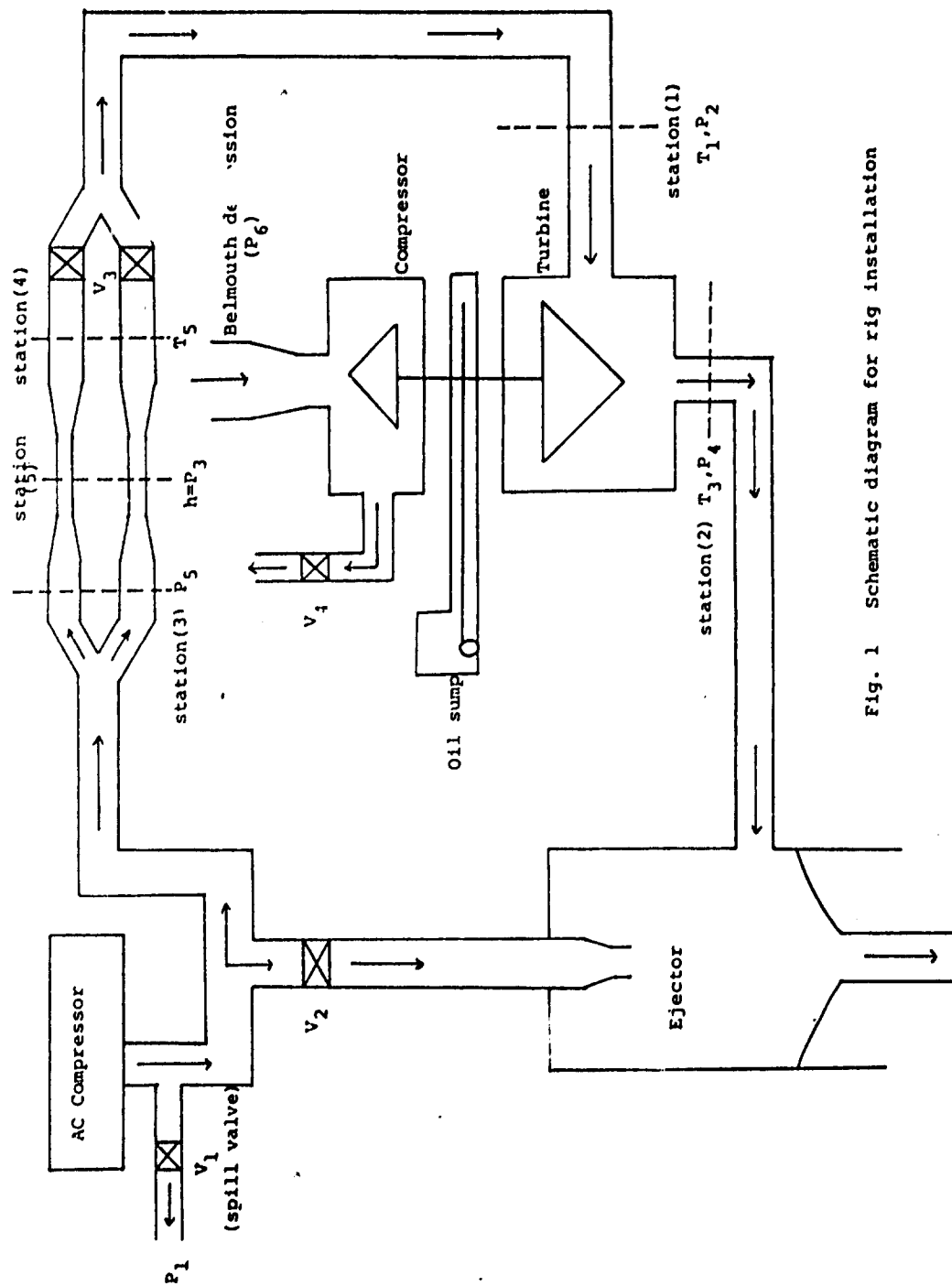NC = Non dimensional speed (rps)

$NC = NA / Sqrt (T_1 + 273.15)$
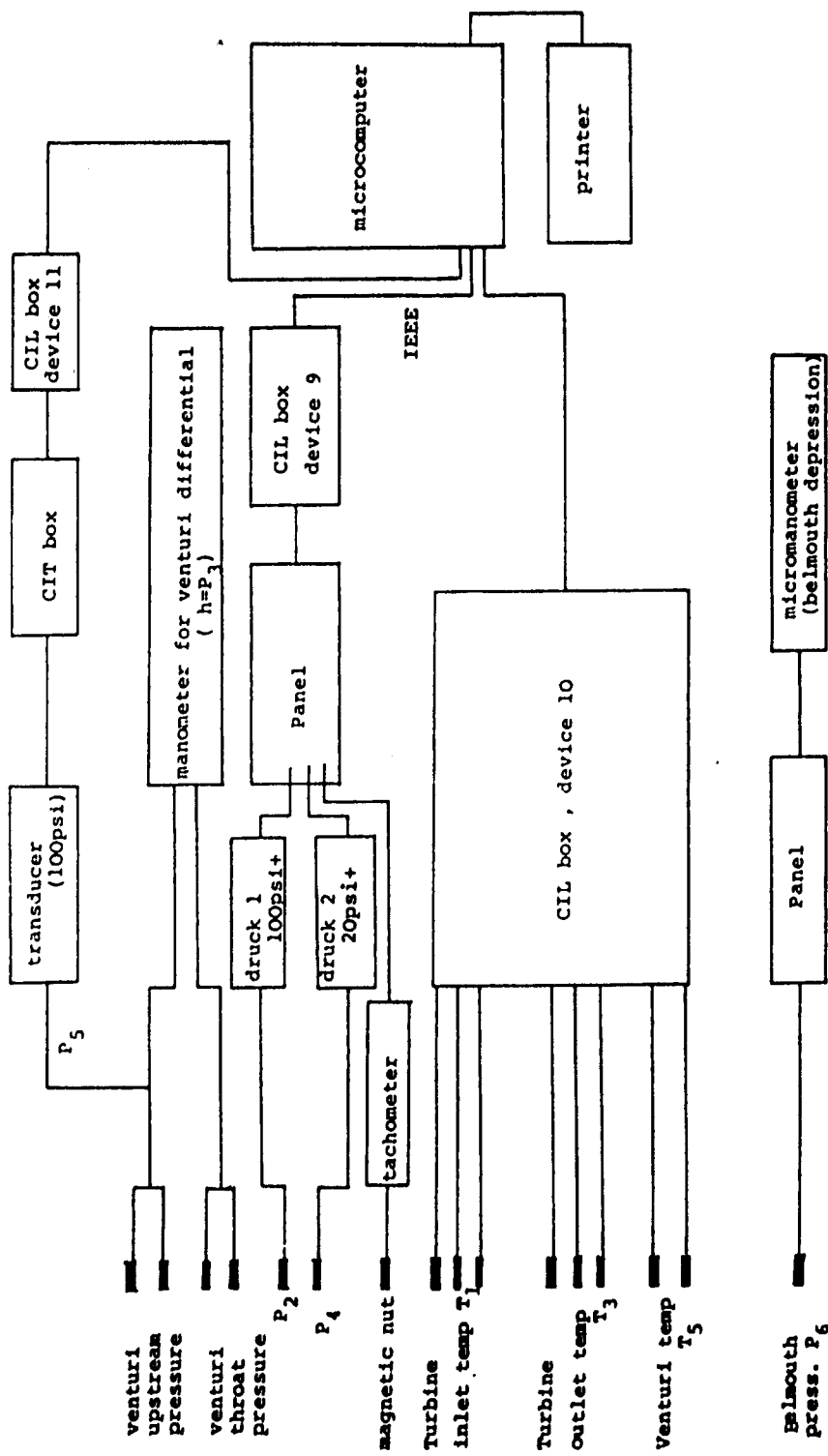
Fig. 1   Schematic diagram for rig installation

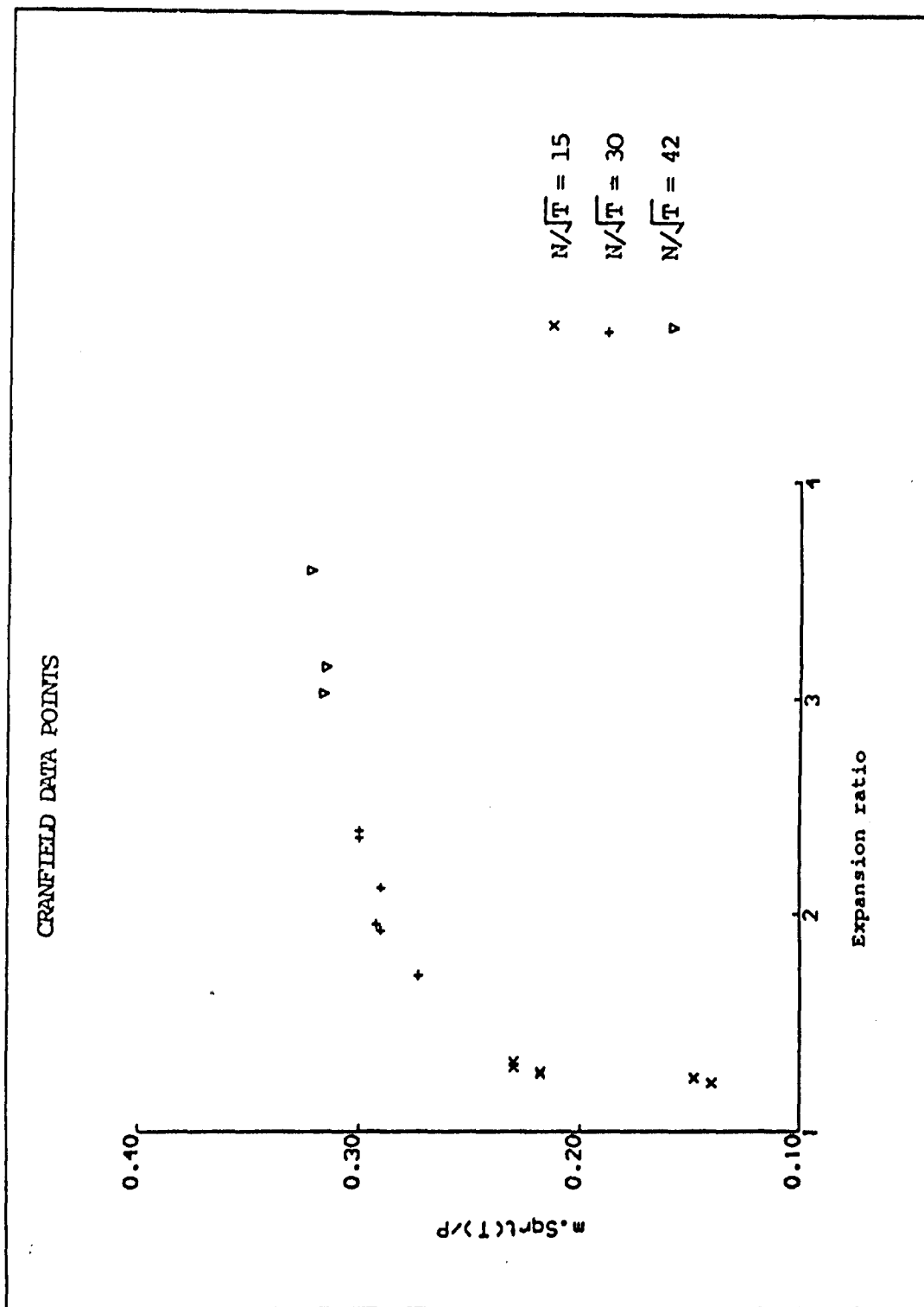Fig :2   Data collection scheme for TURBOMACH turbine performance mapping.

CRANFIELD DATA POINTS

$N/\sqrt{T} = 15$ $\times$

$N/\sqrt{T} = 30$ $+$

$N/\sqrt{T} = 42$ $\triangleright$
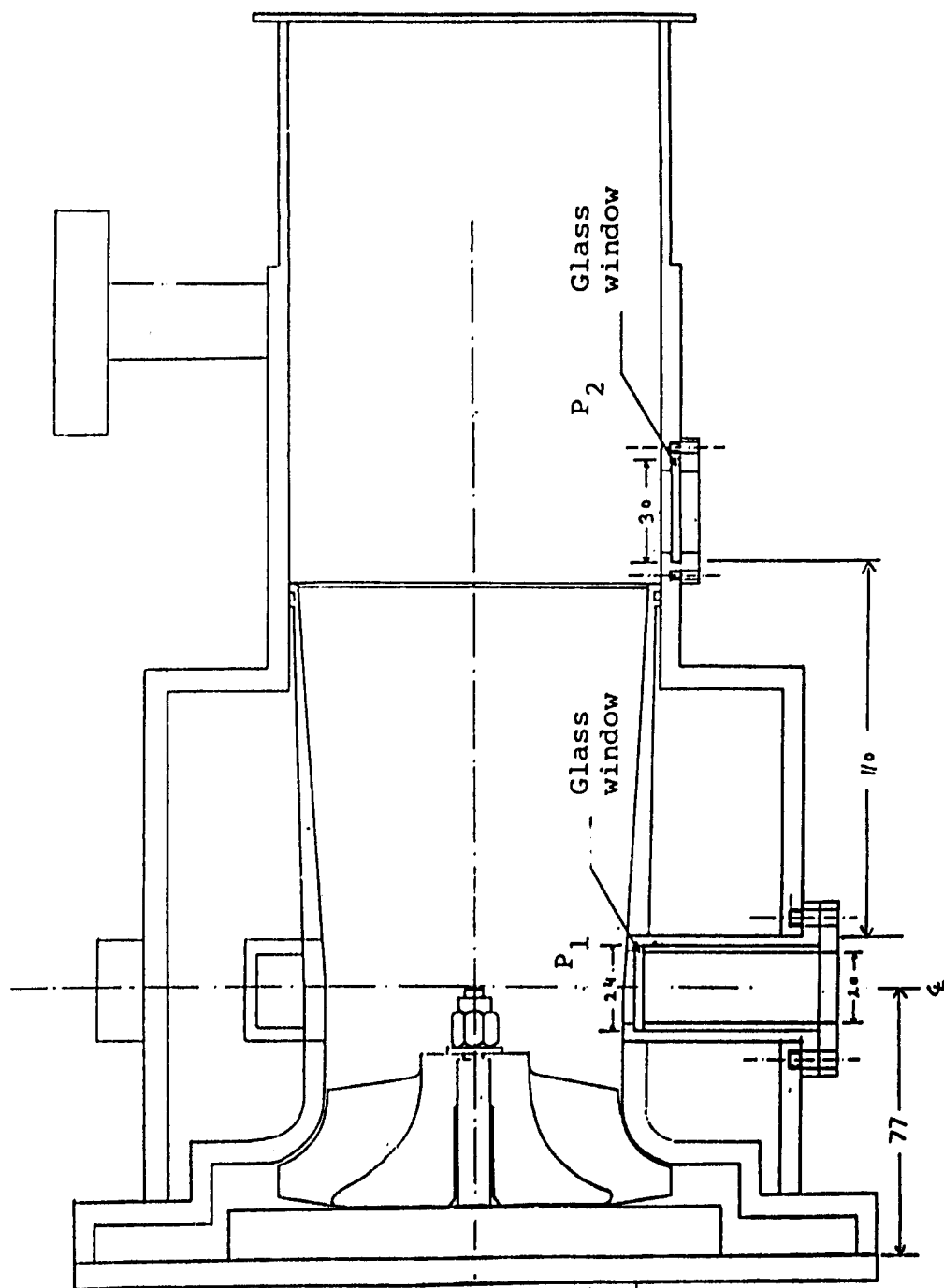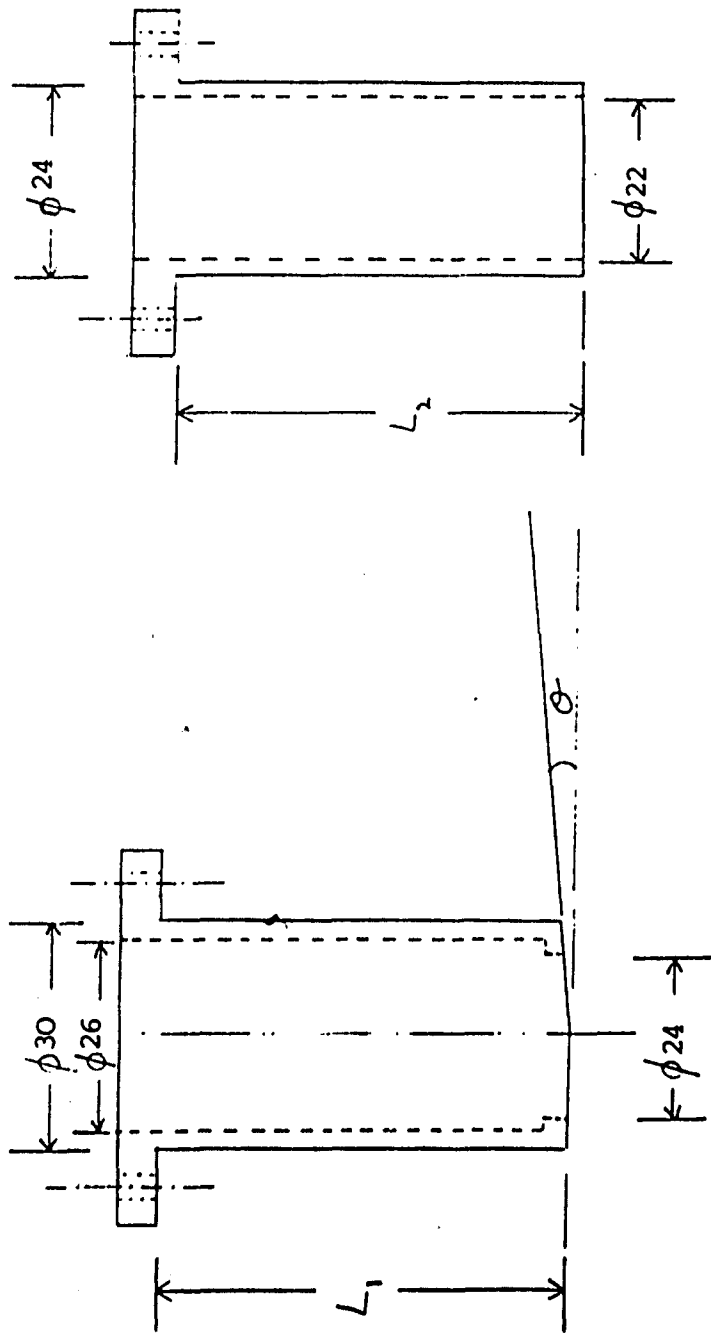
Expansion ratio

$m.Sqrt(T)/P$

FIG :3   Turbine characteristics for three different speeds.

FIG; 4 Optical window positions (P_1, P_2) downstream the turbine rotor.

FIG(a): Tube to hold the glass window

L_1: Length to fit the tube at position P_1 (fig5).

θ : Angle to suit the cone angle in the turbine assembly.

FIG(b):Tube to fix the glass window at its position in fig(a)

L_2: Length to suit the tube in fig(a).

FIG: 5 Design for the tube to hold the glass window